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Computer Modeling Techniques for Array Antennas on Complex Structures

by

D. C. Jenn

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13. ABSTRACT (Maximum 200 words)

This report discusses the suitability of using several existing computational electromagnetics (CEM) codes for modeling antennas on complex structures. Complex structures are those with curved surfaces, edges, protrusions, and composite materials. Several models for wire and slot radiating elements have been developed. The performance of individual elements and arrays of elements over finite flat and curved ground planes is evaluated.

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1.0 INTRODUCTION

During the 1980s several government agencies funded the development of computational electromagnetics (CEM) codes, primarily driven by the interest in radar cross section. These codes are readily available and with some minimum modification can be adapted to antenna problems. They are generally capable of handling arbitrary geometries and materials. Furthermore, pre- and post-processing programs have been developed to generate the platform geometry and view the computed results.

As applied to antennas and electromagnetic systems (i.e., radar, communication, and electronic warfare systems), CEM codes are can be divided into two broad categories. The first category are those used to perform detailed antenna design and analysis. Codes in this category must be able to predict the effects of subtle geometric and material variations on the antenna performance. The primary figures of merit for antenna performance include:

1. gain
2. sidelobe levels
3. voltage standing wave ratio (VSWR)
4. bandwidth

Other figures of merit may exist depending on the functions that a particular system requires of the antenna. Examples are:

1. beam crossover level and coupling (for multi-beam antennas)
2. pointing accuracy
3. power handling capability
4. size, weight, volume, and cost

Codes in this category are generally used in the early stages of the design process to perform tradeoff studies.

The second category of computer codes are those used to predict the antenna's performance when it is in its operational environment; that is, when installed on the platform with other objects near it or in its field of view. These codes must be able to adequately model the interfering objects, an ability which generally occurs at the expense of the detailed antenna modeling capability. This is not due to any shortcoming in the electromagnetic theory, but it is a computational limitation imposed by the need for computer memory or practical computation times. In the second case, the impact on system performance is usually described by the change in the antenna pattern relative to what it would be in the isolated environment.

The objective of this research is to investigate the suitability of using several existing CEM codes in modeling antenna problems of the second type. Several models for wire and slot radiating elements have been developed. The performance of individual elements and arrays of elements on complex structures has been computed using electromagnetic patch codes. Complex structures are those with curved surfaces, edges, protrusions, and composite materials. The computed results are compared with measurements or data from other validated codes to establish the patch model accuracy.

2.0 SURVEY OF CODES

Several frequency domain computational electromagnetics (CEM) codes have been examined. They are broadly grouped into the categories of approximate (physical optics and ray tracing) and rigorous (method of moments). The codes and their capabilities are summarized in Figure 1.

Method of moments (MM) calculations have been made with the code PATCH [1]. It uses triangular subdomains originally developed by Wilton, Rao, and Glisson [2]. Similar codes were developed by Lincoln Labs [3] and McDonnell Douglas [4]. To apply the MM technique the scattering target must be discretized into a collection of triangular facets. The MM procedure is used to compute the current flowing on each facet for a given excitation condition. The excitation can be a plane wave if the antenna is receiving. Various types of current and voltage excitations can be applied to the antenna structure if the antenna is transmitting. Once the currents are determined, the radiated or received field is computed by an integration. The method of moments reduces the EM solution to a matrix problem. Thus the size of the structure and antenna that can be analyzed is limited by computer memory.

Facet models can be generated using a computer aided design (CAD) program named ACAD (Advanced Computer Aided Design) [5]. ACAD can read files in the IGES (International Graphics Exchange Standard) format, and therefore is capable of using databases generated by all of the major commercial CAD programs such as Autocad or Versacad. The antenna and platform configurations are relatively easy to change using a CAD program, which simplifies investigations into the effect of antenna location and body material composition on antenna performance.

When an antenna is installed on a platform, the antenna can illuminate a portion of the platform surface. Current is induced on the surface setting up a scattered field. The scattered field in turn illuminates the antenna, which affects the current distribution on the antenna, and hence the original field incident on the platform surface is changed. When the antenna surfaces are included in the MM patch model, then all of these interactions between the antenna and platform are included in the computation

NAME	TYPE	ADVANTAGES	DISADVANTAGES
PATCH (Sandia Labs)	rigorous (MM)	• all frequencies • surface impedance • wide range of excitations • open source code	• computer limitations
CARLOS-3D (McDonnell Douglas	rigorous (MM)	• wide range of electric and magnetic materials • direct interface with ACAD • all frequencies	• current version only does scattering • radiation version in development • computer limitations
FERM (Lincoln Labs)	rigorous (MM)	• wide range of antenna excitations • multiple matrix solvers • all frequencies	• limited geometry generator • no source codes limits development • computer limitations
NEC-BSC (Ohio State)	approximate (GTD & GO)	• fast solutions • geometry viewer	• limited to high frequencies • crude geometry models • crude antenna models • some scattering mechanisms missing • no antenna/platform coupling
APATCH (Demaco)	approximate (PO & SBR)	• interfaces directly with ACAD • detailed target models possible	• limited to high frequencies • no antenna/platform coupling • crude antenna models

MM = method of moments;PO = physical optics; GTD = geometrical theory of diffraction; GO = geometrical optics
ACAD = advanced computer aided design; SB = shooting and bouncing rays

Figure 1: Summary of computer codes investigated for use in modeling array antennas on complex structures.

of current. The higher order coupling between the antenna and its environment generally has only a minor effect on the radiation pattern. However, antenna coupling with objects in its near field can significantly affect the VSWR.

Approximate codes ignore the higher order coupling, or approximate the higher order contributions by a series of correction terms. Examples of this type of code are APATCH [6] and NECBSC [7]. APATCH combines the physical optics approximation with the shooting and bouncing ray technique to estimate multipath effects. NECBSC is based entirely on microwave optics.

3.0 RADIATING ELEMENT AND ARRAY MODELS

The following antennas have been modeled to demonstrate the capabilities of PATCH:

- thin-wire dipoles
- crossed dipoles
- slots
- horns
- microstrip patches
- fat dipoles
- cavity-backed crossed dipoles
- ground plane shape and extent

Typical results for each type of element are presented. The units labeled in the figures are in wavelengths times 100 unless otherwise noted. Also, the pattern curves are not normalized to gain (the quantity 20 $\log(|\vec{E}|)$ is plotted).

3.1 DIPOLE RADIATING ELEMENT

The radiation pattern and input impedance was computed for an isolated dipole in free space, a dipole over an infinite ground plane, and a dipole over a finite ground plane. Both strip and cylindrical models were investigated. The strip model (Figure 2) provided accurate results with a minimum number of edges. (This is a form of the well known "thin-wire approximation.")

Figure 3 shows a linear array of dipoles above a finite ground plane. The radiation patterns of the array are shown in Figure 4 and compared to those for an array of dipoles over an infinite ground plane. Figure 5 compares several of the individual element patterns. These plots clearly illustrate the mutual coupling variation with element location.

Figure 6 shown a two dimensional array of dipoles. Diagonal plane patterns are shown in Figure 7.

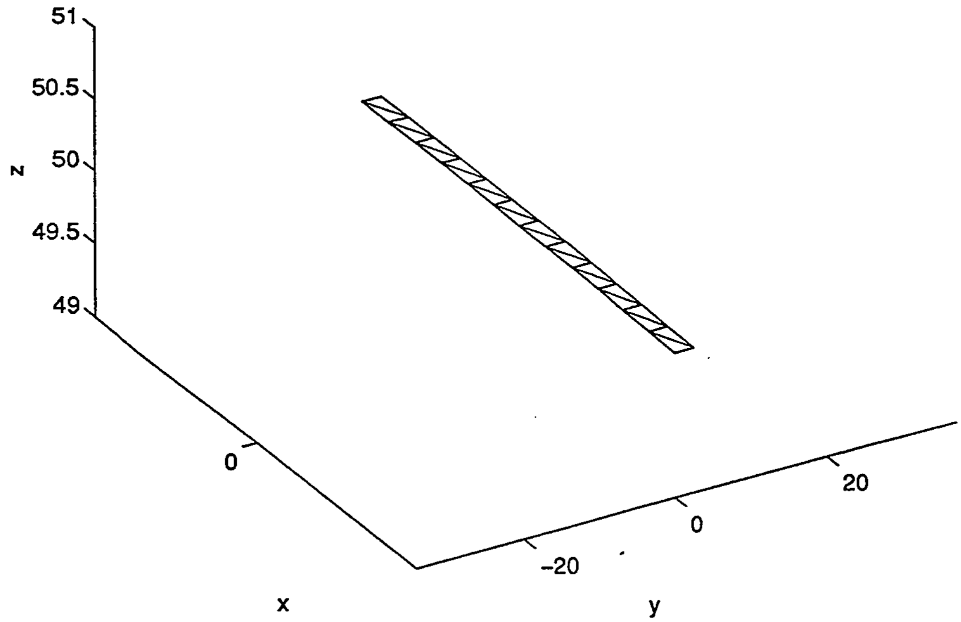


Figure 2: Strip model of a dipole with a radius much less than a wavelength.

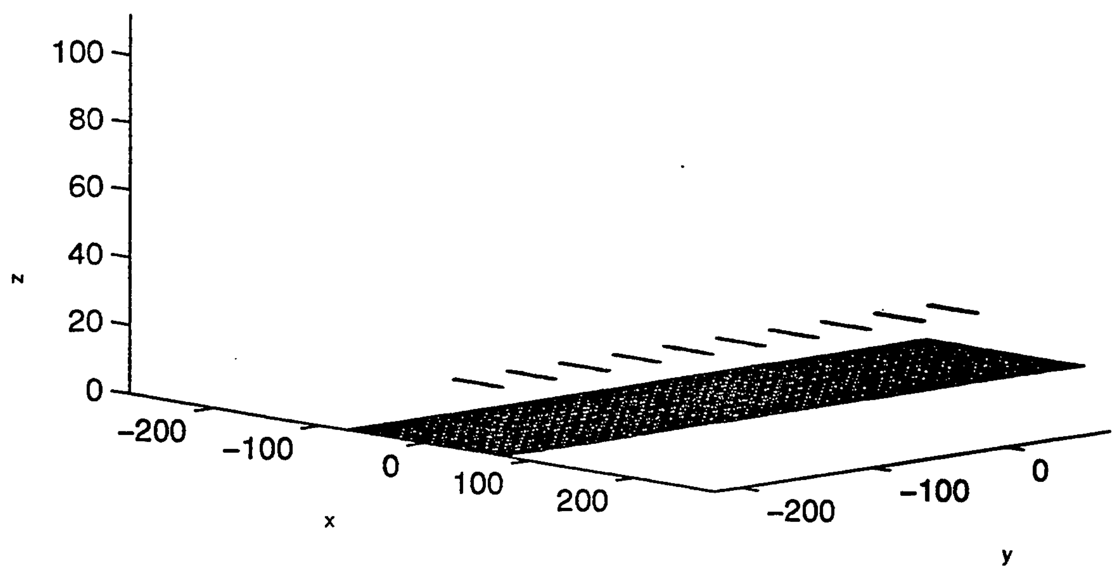


Figure 3: Linear array of dipoles.

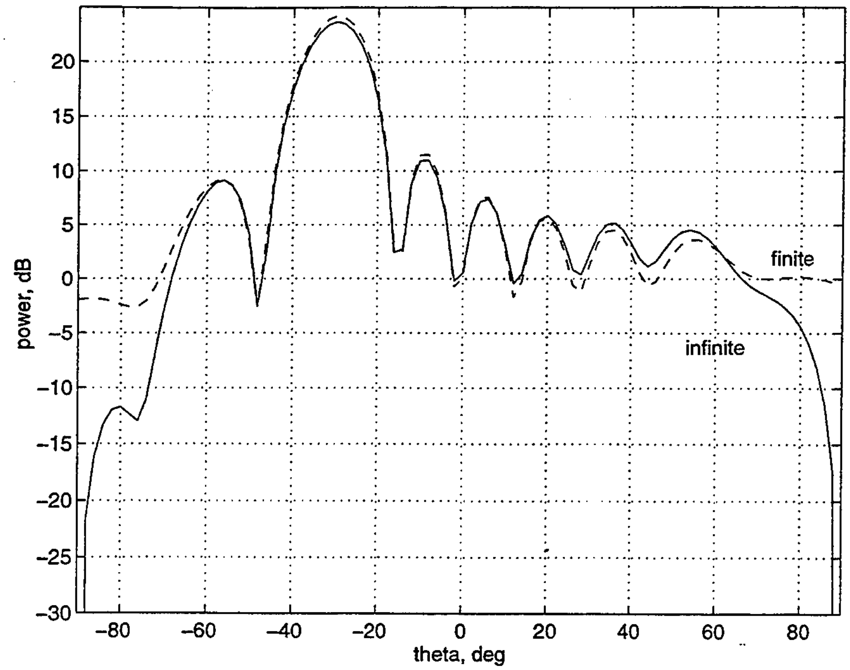


Figure 4: Linear array radiation patterns (finite vs infinite ground plane).

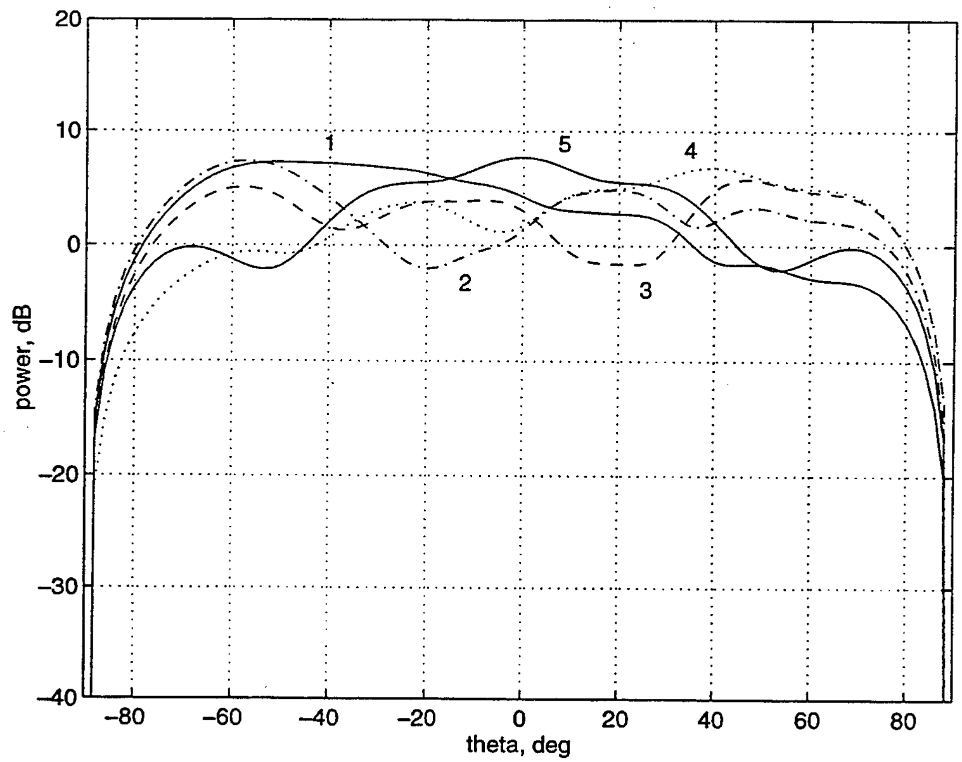


Figure 5: Active element patterns vs location in the array (1 is at edge).

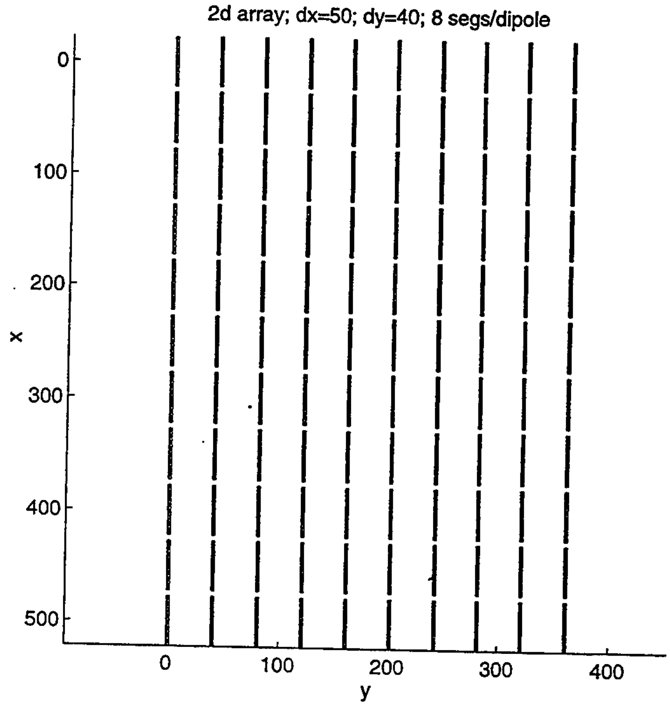


Figure 6: Two-dimensional array of dipoles.

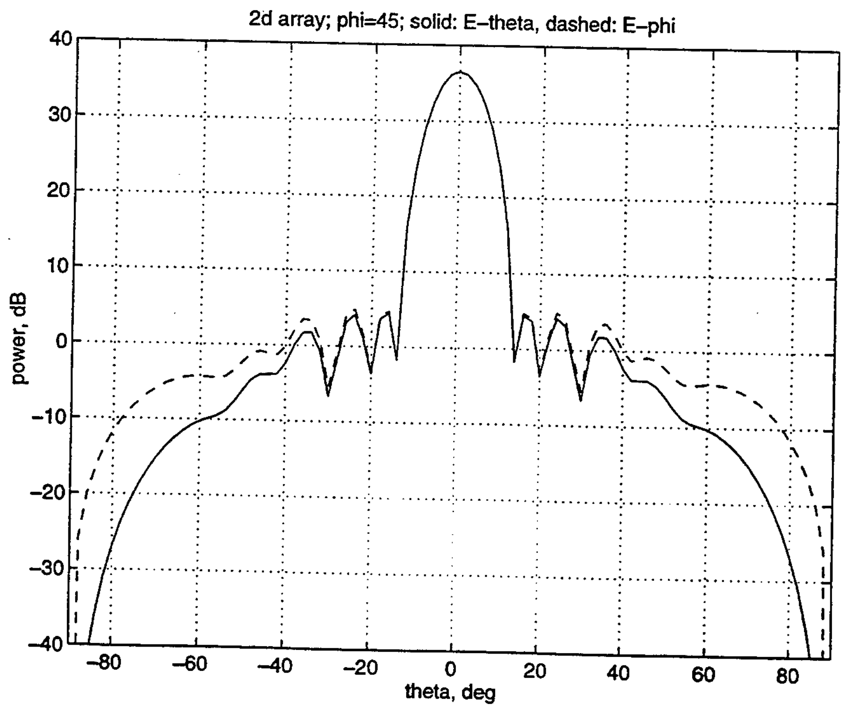


Figure 7: Diagonal plane patterns for the two dimensional array.

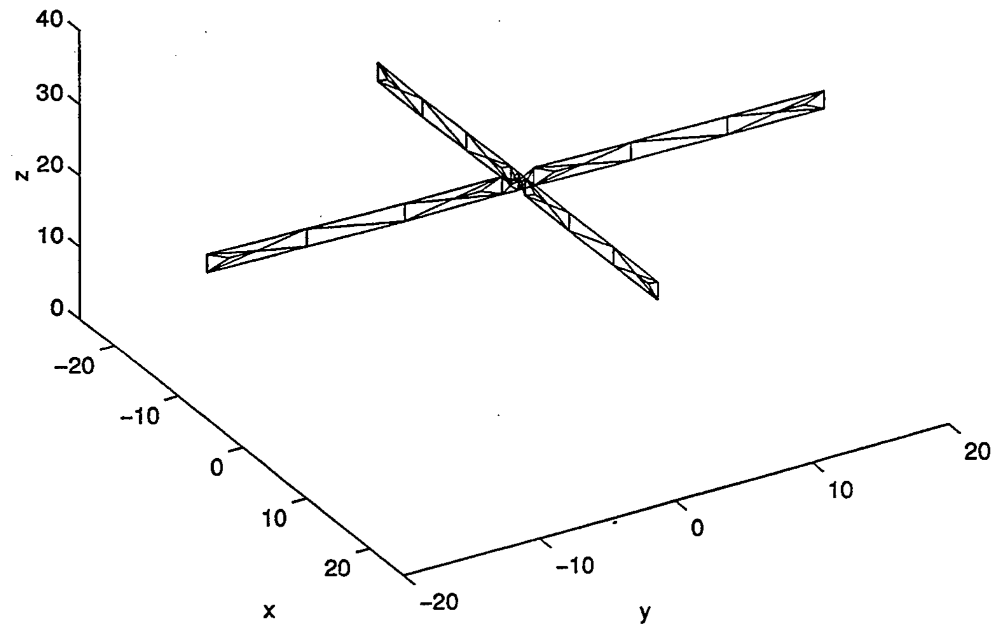


Figure 8: Crossed dipole patch model.

3.2 CROSSED DIPOLE RADIATING ELEMENT

A crossed dipole model is shown in Figure 8. The center slots of the two dipoles are fed in phase quadrature to obtain circular polarization. Figure 9 shows the radiation pattern of a 7 element array over an infinite ground plane. Rotating linear polarization is simulated to generate the pattern.

3.3 SLOT RADIATING ELEMENT

A radiating slot is simulated by exciting a triangle edge. A plate with "hard-wired" (fixed) edge locations is shown in Figure 10. Typical element radiation patterns appear in Figure 11.

3.4 HORN

A horn can be approximated by an array of slots in a plate located in the aperture of the horn. The amplitudes and phases of the slots are tapered to provide the appropriate beamwidth and sidelobe level. A slot model of a Microline exponentially tapered horn is shown in Figure 12 and the E-plane radiation pattern is compared to measured data in Figure 13. The phase center of the slot model will not necessarily correspond to the horn aperture. Thus, when this model is used in place of the horn, the plate must be located at the horn phase center [8].

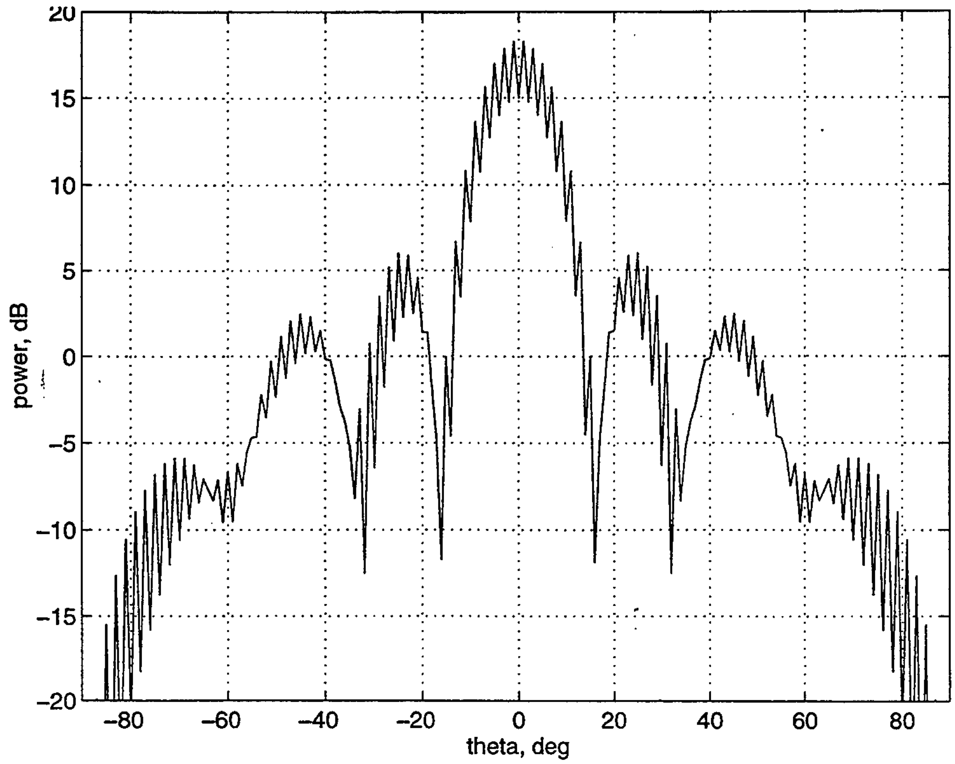


Figure 9: Radiation pattern of a 7-element crossed dipole array (rotating linear polarization simulated).

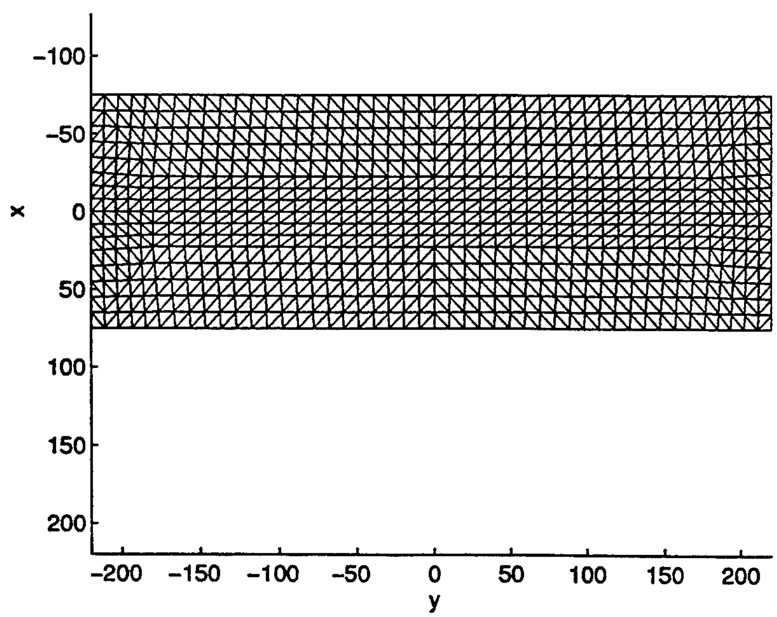


Figure 10: Ground plane with edges introduced for excitation (central portion).

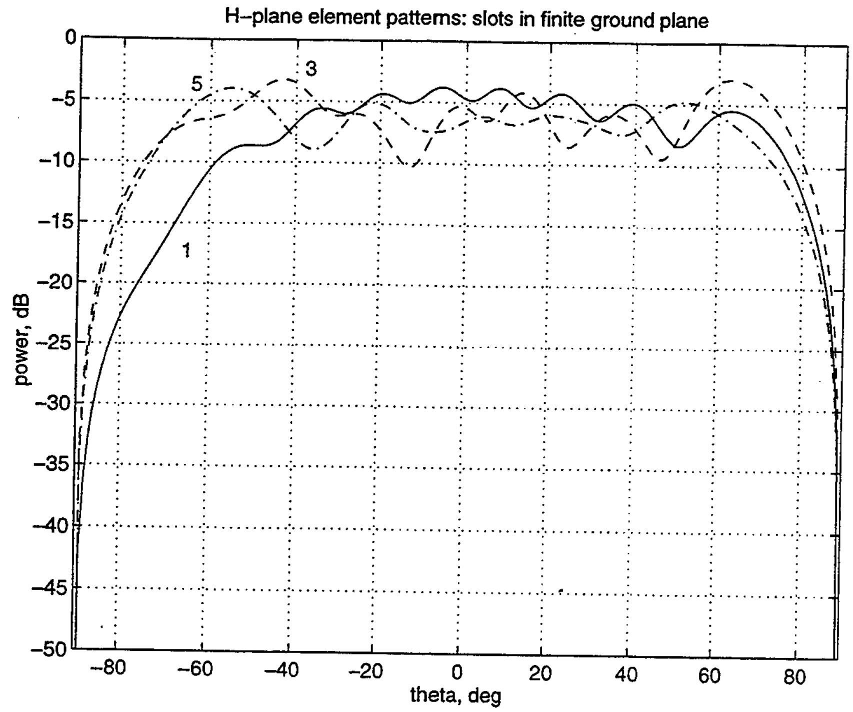


Figure 11: Element patterns for several slots in the array.

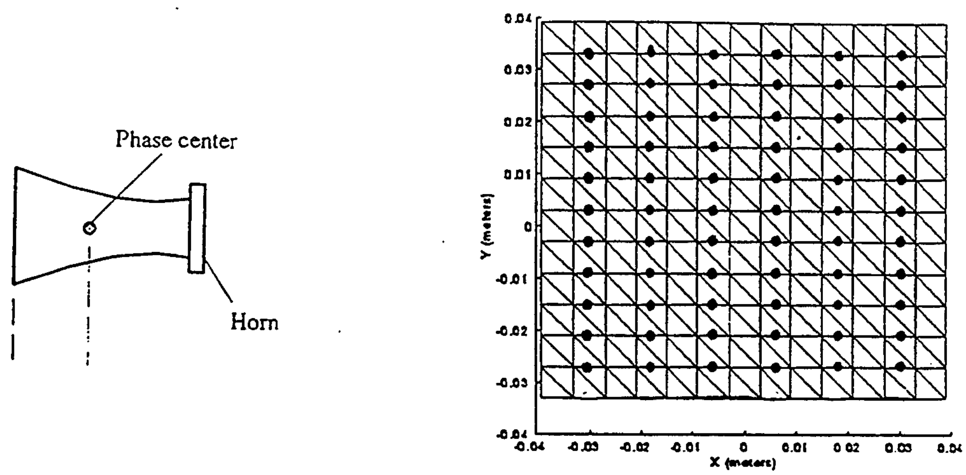


Figure 12: Horn antenna with aperture slot model (dots indicate excited edges).

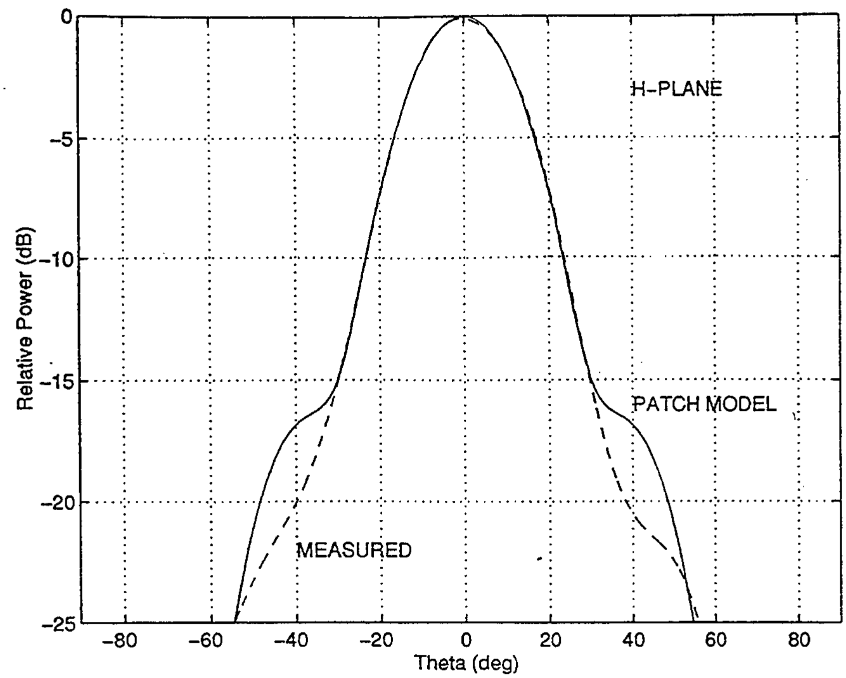


Figure 13: Comparison of the radiation patterns for the horn and slot model.

3.5 MICROSTRIP PATCH RADIATING ELEMENT

Microstrip patches are widely used in conformal antennas. The radiator is comprised of a conducting patch suspended above a ground plane as illustrated in Figure 14. Several approximate patch models were investigated. Figure 15 shows two such models: a high-fidelity model with many edges and a more crude model with few edges. The central edges are excited in such a way as to approximate the surface current that actually exists on the patch. The impedance is computed by comparing the current and voltage at a point that corresponds to the patch feed point. Both circular and linearly polarized patches have been modeled. Computed pattern and VSWR data agree with published results [9].

3.6 CAVITY-BACKED CROSSED DIPOLES

Figure 16 shows cavity-backed crossed dipoles. The cavity rims serve to narrow the beam relative to that obtained with a flat ground plane. It also significantly reduces the cross polarized field component. Figure 17 shows the principal plane patterns.

3.7 FAT DIPOLE

Figure 18 shows the body of a miniature unmanned air vehicle (micro-UAV) [10]. The body serves as an antenna that will be used for a telemetry link and wireless

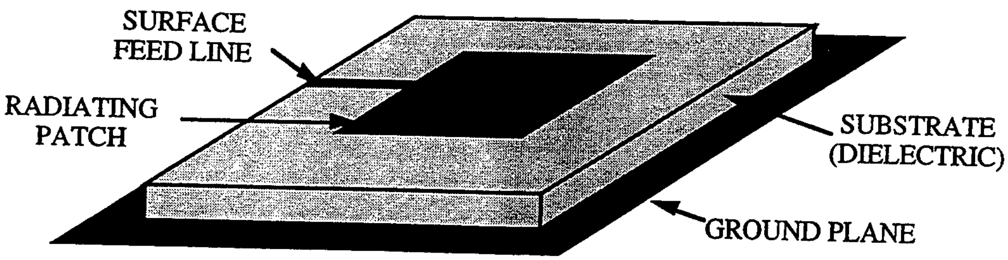


Figure 14: Rectangular microstrip patch antenna with a stripline feed.

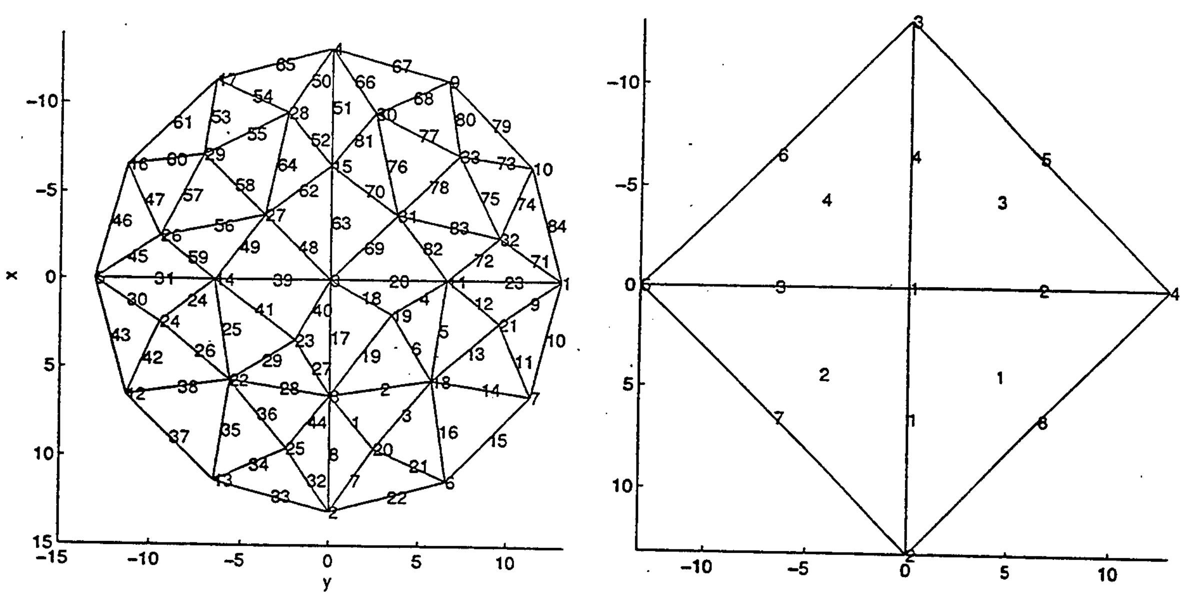


Figure 15: Approximate models of microstrip patches.

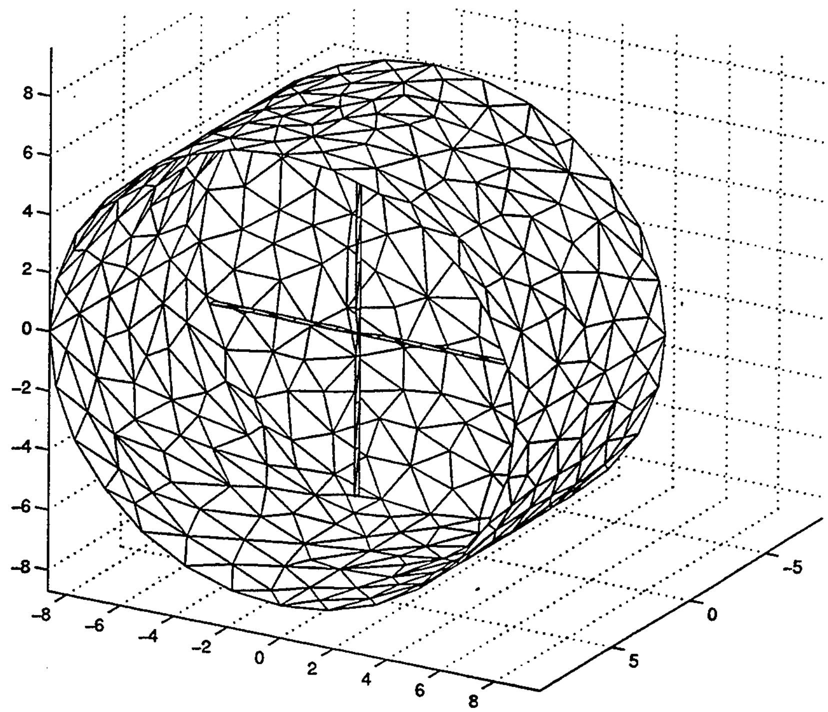


Figure 16: Cavity-backed crossed dipole antenna.

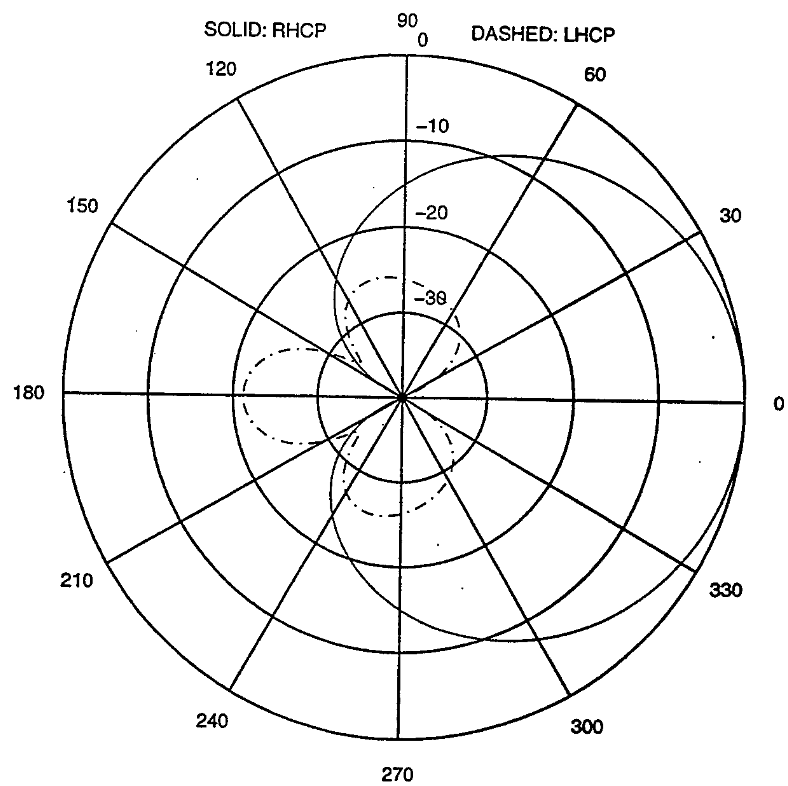


Figure 17: Radiation pattern of the crossed dipole antenna.

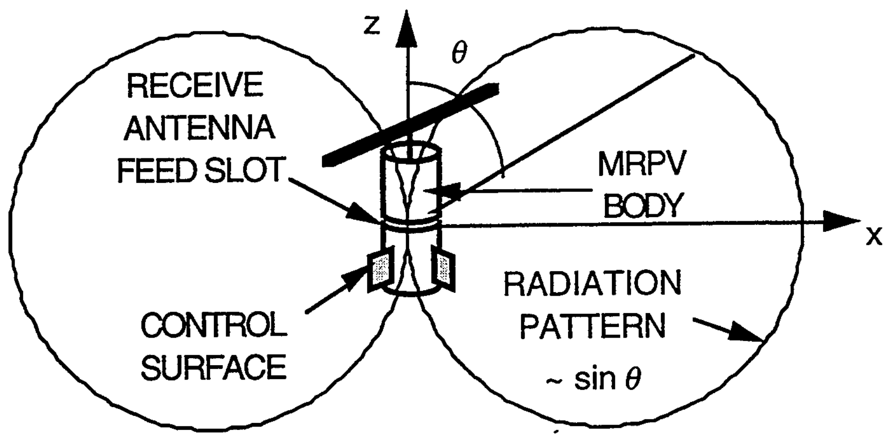


Figure 18: Micro-UAV body which approximates a short fat dipole.

power transmission. This structure is actually a cylindrical "fat dipole." For a fat dipole, the current can vary around the circumference of the dipole. A comparison of the VSWR measured on a prototype vs that computed using the patch model (Figure 19) is presented in Figure 20.

3.8 GROUND PLANE SHAPE

The ground plane shape and extent will affect the pattern of a small array at wide angles. Scattering from an edge is maximum in the plane perpendicular to the edge. By changing the edge angle, the direction of the scattering maximum can be changed, thereby lowering the wide angle sidelobes in the principal plane [11]. This approach may not be acceptable in all circumstances because the scattering is redirected elsewhere, simply moving the lobe, not reducing it. A more effective treatment is to use serrated edge shapes or resistive edge "softening" techniques. An array with tilted ground plane edges is shown in Figure 21. The radiation patterns are shown in Figure 22. As expected, the tilted edge results in a reduction of about 5 dB in the farthest principal plane sidelobe.

Curved ground planes are easily modeled using triangle facets. Figure 23 shows a linear array with a curved ground plane. If the elements are fed in phase the beam is not focused due to the fact that the elements do not lie in a straight line. Phase corrections can be added to refocus the beam as shown in Figure 24.

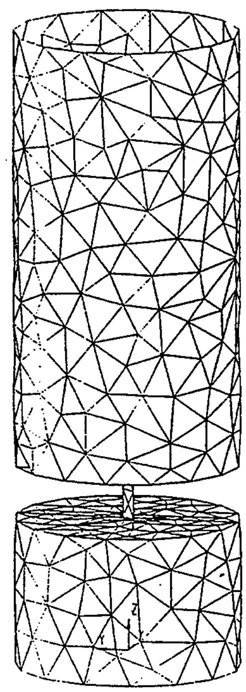


Figure 19: Patch model of the micro-UAV body.

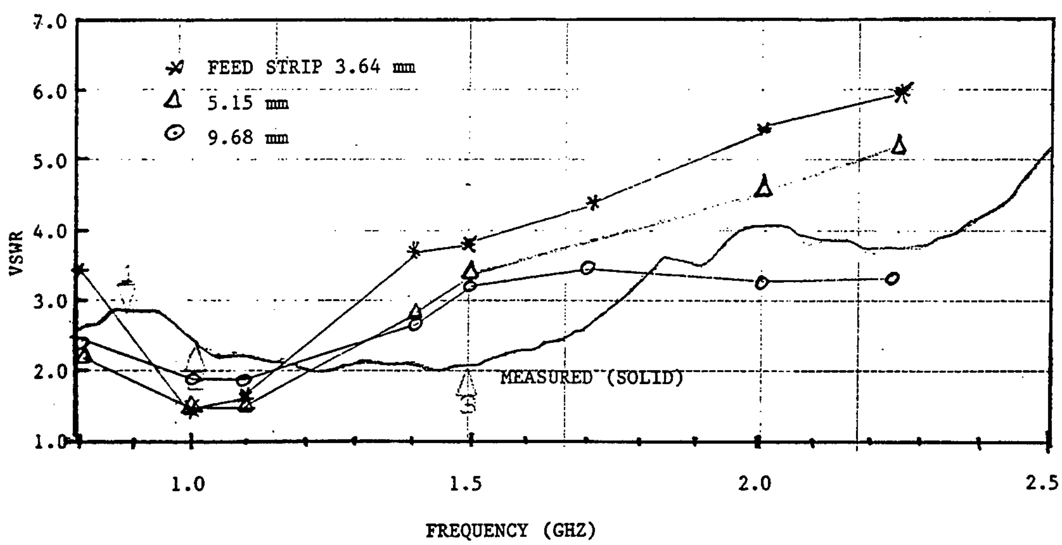


Figure 20: Comparison of computed and measured VSWR.

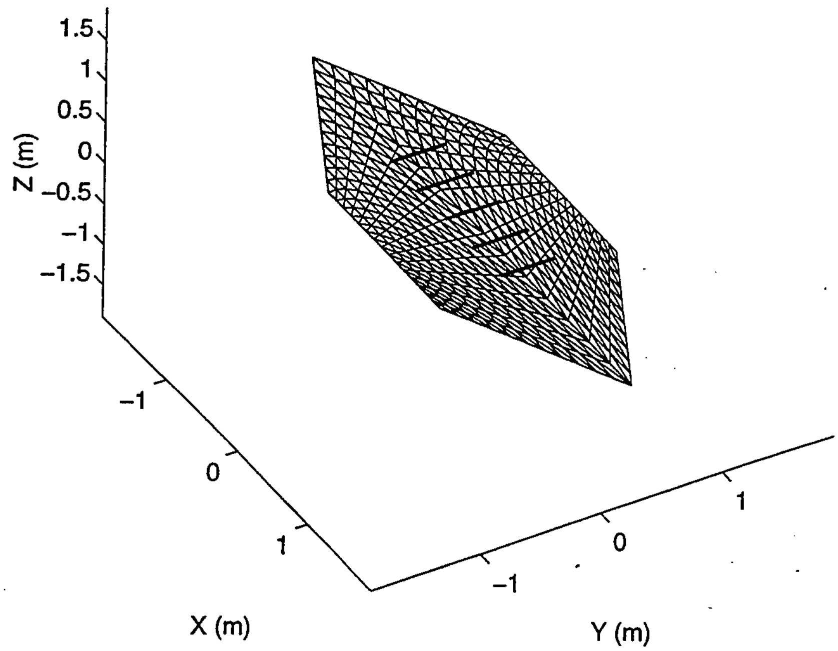


Figure 21: Small array with a ground plane with sloped edges (triangle height 1λ).

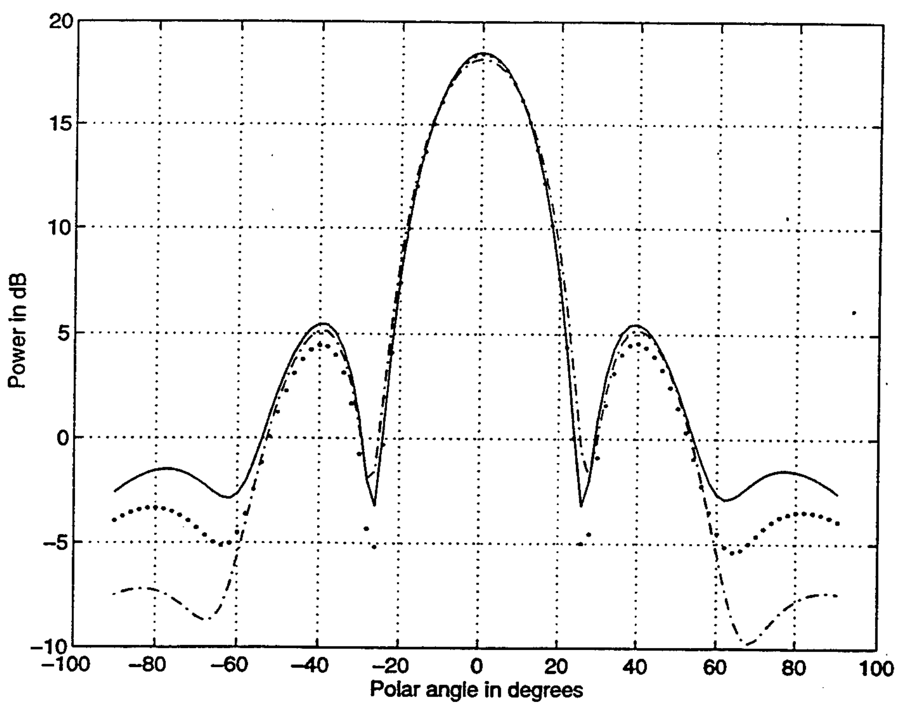


Figure 22: Patterns for arrays with sloped (dotted: 0.5λ height; dash-dot: 1λ height) and parallel (solid) ground plane edges.

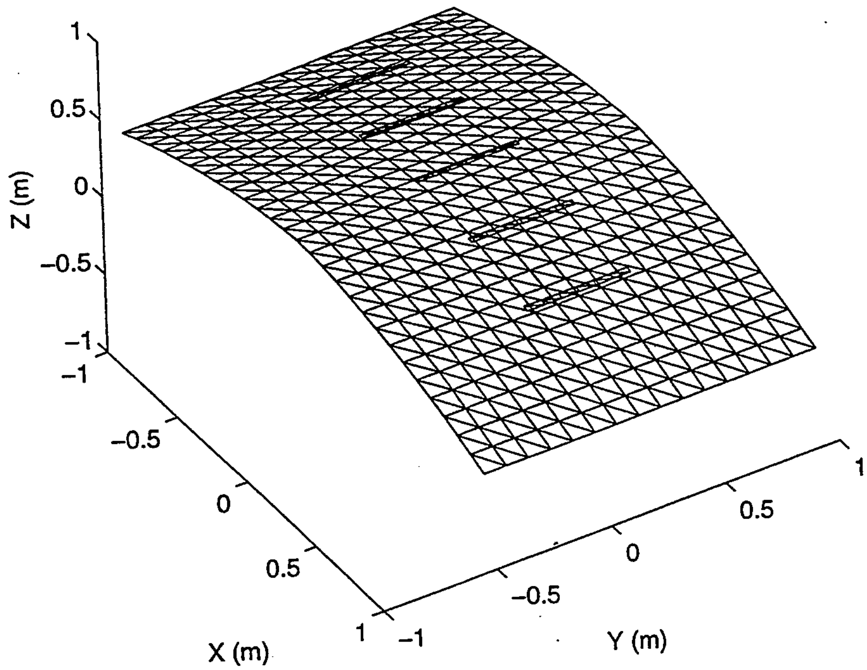


Figure 23: Linear array with a singly curved ground plane.

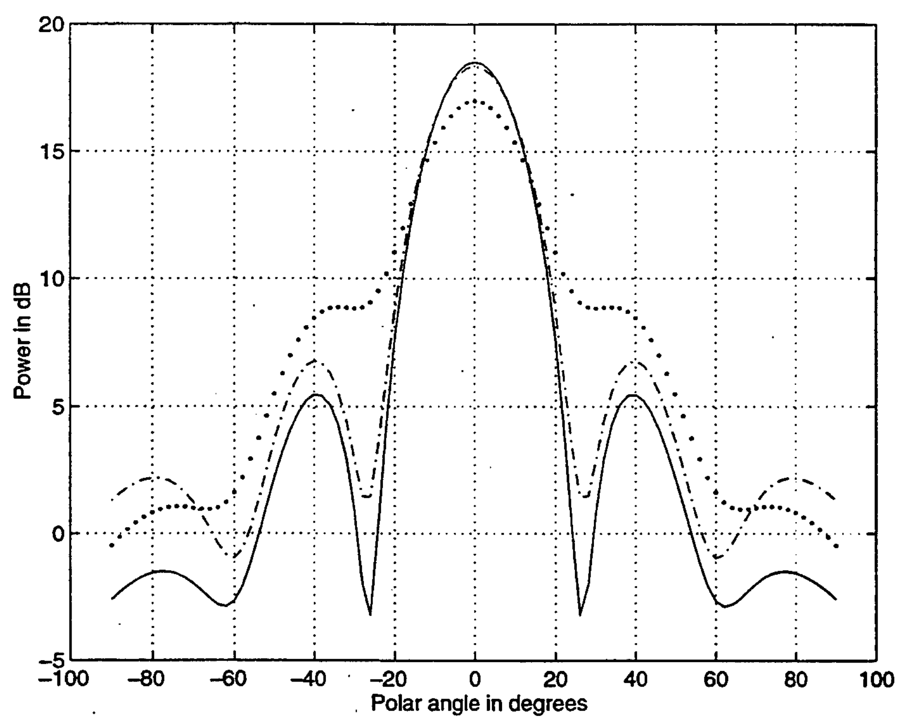


Figure 24: Patterns for arrays with a curved ground plane (dotted: without phase corrections; dash-dot: with phase corrections) and a flat array (solid).

4.0 PLATFORM EFFECTS

CEM codes can be used to model antennas on platforms and structures to investigate changes in the antenna performance due to nearby objects. The pattern changes occur because the platform interacts with the near fields of the antenna. Other effects that may appear due to the platform surfaces include line of sight blockage (shadowing), multiple reflections, and diffraction by edges. For example, Figure 25 shows a F-18 patch model with a data link pod under the wing. It is expected that the pattern of an antenna mounted on the pod will be significantly different when the pod is under the wing vs that when the pod is isolated (not mounted under the wing).

If the frequencies of interest are in the UHF band, then a method of moments code is not a practical approach to solving the problem. A rule of thumb for convergence is that the triangle edge lengths should not exceed 0.1λ. For example, if the frequency is 800 MHz, the wavelength is 0.37 m and the triangle edges should be limited to about 0.04 m (1.6 in). This would require tens of thousands of edges, and approximately the same number of unknowns (simultaneous equations). Even if sufficient memory were available, the computational time would be prohibitive, except possibly on the fastest supercomputers. Thus an approximate method such as APATCH or NEC-BSC must be used.

APATCH has the advantage of using the ACAD generated facet geometry file as input. Multiple reflections are included in the calculation of the current on each facet. Edge diffraction can be added if a edge file is specified. Antennas can be modeled in either of two ways. One is to describe the antenna in terms of simple radiating components such as dipoles and slots. A second is to define a table of antenna pattern values. Either way, the interaction of the currents on the antenna with objects nearby is ignored. That is the current distribution does not change significantly when nearby objects are modified. However, the effects of the nearby objects are included in the calculation of the field at a distant observation point. Thus the effects of shadowing, blockage, multiple reflections and diffraction can be examined using APATCH.

Figure 26 shows two sets of gain contours for a cavity-backed crossed dipole antenna located on the pod. The bottom is right-hand circular polarization; the top is left-hand circular polarization. The axes are azimuth and elevation angles, where Az=0 and El=0 is aft. Looking aft from the aircraft, positive elevation is up and negative elevation is down. Azimuth is measured in the zero elevation plane with positive being in a counter-clockwise direction. The dashed contours are the contours for free-flight; the solid contours are the captive configuration.

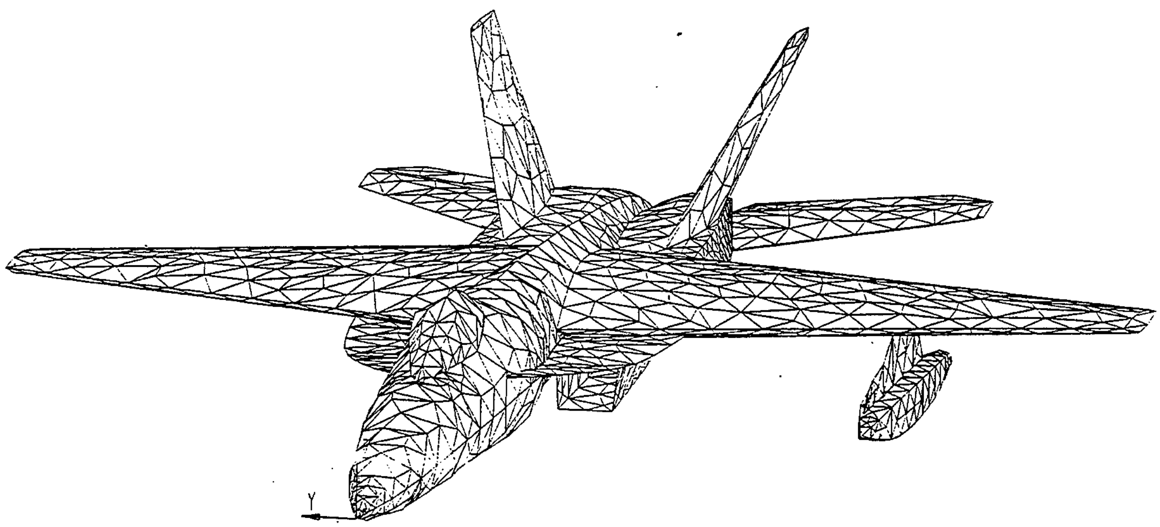
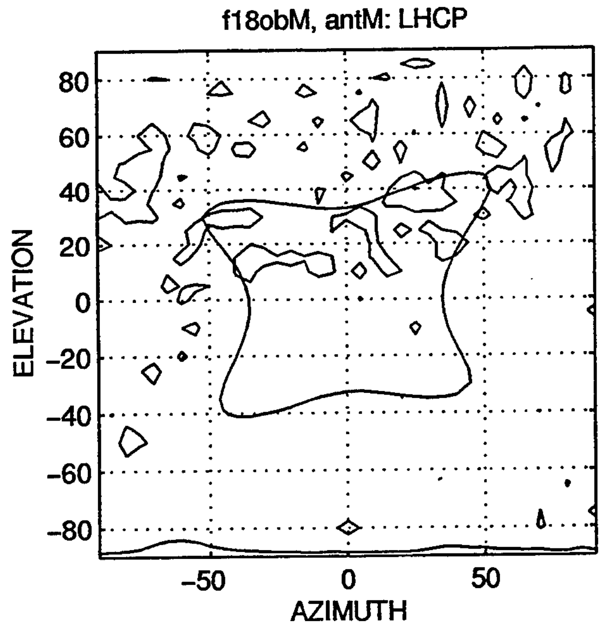


Figure 25: Patch model of a F-18 with a data link pod mounted under the wing.



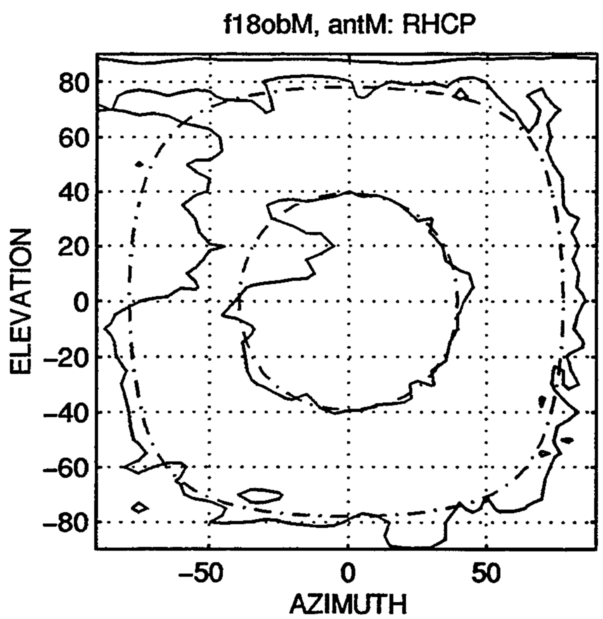


Figure 26: Gain contours for the isolated data link pod (smooth curves) vs when it is in the captive configuration (jagged curves).

5.0 SUMMARY

Several "off-the-shelf" CEM codes have been used to model a wide range of antenna problems. They include simple dipoles and slots as well as microstrip patches and horns. These codes are well suited to the evaluation of antenna gain and pattern characteristics under various operational conditions. The purpose of this research was to demonstrate some of the features of the codes that are of use in the the design and analysis of antennas on complex structures. The computer programs are not as useful in the design of the antenna itself because the codes are generally not able to model the fine details of the antenna feed and materials, which are crucial for predicting resonance conditions.

Many of the codes are derivatives of RCS prediction codes, and have been thoroughly validated. Furthermore, pre- and post-processing tools have been developed to generate geometry models and visualize data. All of the codes examined in this study are available free to government agencies and contractors. (In some cases training or shipping and handling charges may be required.)

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